Complementarity of acquisition techniques for the documentation of Neolithic engravings

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Complementarity of acquisition techniques for the documentation of Neolithic engravings: lasergrammetric and photographic recording in Gavrinis passage tomb (Brittany, France).

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Highlights:

- We compare laser and photographic recording techniques designed for megalithic art.
- Processing of 3D points cloud highlights both forms and context of engravings.
- Chronological relationships between overlapping motifs are identified.
- DStretch colour program is used to identify and record very faint pecked engravings.
- Laser and photographic techniques complement each other and should be combined.

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The Neolithic tomb of Gavrinis is very famous for its rich and complex engraved art that has inspired a huge number of interpretative works, which, however, were all based on unsatisfying drawings. This article describes the methodological results of a new recording program of Gavrinis engravings that combines 3D laser and 2D photographic techniques. Laser scanning are not only aimed at giving accurate contextual information such as the stone relief and architectural setting in which the art is found: a specially designed processing of the points cloud also allows to highlight the contours of the pecked motifs and to record them directly from the 3D model of the decorated stones. This can be further improved by dedicated photographic recordings using oblique lights and image processing techniques in order to gain more detailed recordings of the motifs as well as insights into their chronological relationships. In the unusual case of barely visible engravings made with very slight peckmarks, experimental application of DStretch colour detection program has given unexpectedly good results. A comparison of all these results shows that laser and photographic techniques have different strengths and weaknesses that complement each other. Therefore, a combined use of these techniques within a single methodological process allows to produce cutting-edge and comprehensive documentation of Neolithic tomb art.

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The megalithic passage tomb on the small island of Gavrinis (Larmor-Baden, France ; Fig. 1) is one of the most famous Neolithic monuments in Europe for the quality and quantity of the abstract and figurative motifs that were engraved with pecking on the wall surface of its inner chamber. Since the 19th century the art has been interpreted in many different ways through innumerable scholarly papers, however all these interpretations were based on varying drawings by archaeologists or artists representing the art. The best recordings currently available were made 50 to 30 years ago from direct tracing (Shee Twohig 1981; Le Roux 1984), a technique that often misses details of the engravings and, in all cases, gives only a schematic view of the morphology of the stone on which the art was made.

A new program of photographic recordings of the engravings-was initiated in 2009 and was later complemented with lasergrammetric recordings from 2011 (photogrammetric recordings, experimented from 2012, will not be discussed in this article ; see Lescop *et al.* 2013). Both techniques (lasergrammetry and photography) were used in combination to record both the art and the stone relief in a very accurate way. The resulting data have been incorporated into a single digital model, which allows for the first time a total recording of the decorated stones.

During the process, which was in large part experimental, the enhancing capacities of the two techniques were explored and compared in order to assess their ability to unveil unknown details of the engravings as well as chronological relationships within groups of signs. A third technique, using photograph colorimetry, has been successfully experimented to identify very faint pecked motifs made on sandstone where other techniques failed.

The article proposes to review these three documentation processes and to show how a combined use of them is essential for a detailed and accurate recording of both engraved and natural surface data in Neolithic tombs. Such data change entirely our perception of the decorated stones and bring a completely new basis to the interpretation of the art at Gavrinis.

1. The Neolithic passage tomb of Gavrinis

The monument was built on the southern end of the island of Gavrinis, which is located at the estuary of the Vannes river. It consists in a large circular stone cairn (50 m. wide, 7,5 m. high, 6980 m^3) covering an internal megalithic structure 16 m. long composed of a quadrangular chamber (5,5 sq. m.) and an access passage leading to the outside (Fig. 2), which is a usual design of megalithic chambered tombs in Neolithic western France (L'Helgouac'h 1965; Giot 1990). All the wall, floor and ceiling surfaces of the internal structure are made of granite, migmatite, orthogneiss, quartz and sandstone slabs. Out of the 29 wall's orthostats 24 are engraved.

Though an access to the chamber from the top of the cairn was created at least from the medieval time, the official recognition of the site and the first description of the engravings date only to the early 19th century (Mérimée 1836). Following this, several excavations by Gustave de Closmadeuc (1884, 1886) allowed the completion of a first inventory of the engraved signs in Gavrinis (Closmadeuc 1873). More recent excavation by Charles-Tanguy Le Roux (1985) focused on the structure of the cairn. Subsequent restoration works resulted in the discovery of new spectacular carvings (Le Roux 1984), including a horned animal represented on the upper face of the chamber capstone. It was then realised that this stone was one broken piece of a large slab re-fitting with another decorated broken piece found 3,5 km away over the chambered tomb of La Table des Marchands in Locmariaquer (Closmadeuc 1885; Le Roux 1984). Both fragments were part of a same monumental stele which, before being reused in the construction of the two tombs, was standing in a large stone row of which the famous broken Grand Menhir at Locmariaquer is the only *in* situ remaining element (Cassen, L'Helgouac'h 1992; Cassen 2009).

2. Objectives of the recording program

The new recording program of the engravings and architecture at Gavrinis that is described in this article was initiated in 2009 as part of the ANR-funded JADE project (Pétrequin *et al.* 2012). It has been subsequently expanded in a dedicated collaborative project (2011-2013) between members of the CNRS and Nantes national school of architecture.

The main objective of the program is to create a new comprehensive corpus of the symbolic representations engraved in Gavrinis that also integrates their architectural context. To do so the program aims at improving the constant relationship – in archaeology, and in particular in any iconographic study – between acquisition, representation and interpretation of field data. In this respect, the setting up of new recording techniques and methods for Neolithic art is crucial to the renewal of the documentation, and consequently interpretation, of the engravings at Gavrinis.

Inevitably, the conceptual framework recently elaborated in order to re-think the signs and their combinations has an influence on the way these signs are being documented and represented. For example, particular attention is given to hierarchical arrangements, oppositions and correlations of signs within engraved compositions (Cassen 2000). This back-and-forth reflection between methodology and epistemology has been getting more accurate as similar recording works were being conducted in other regional monuments during the last 10 years (Runesto, Mané Croc'h, Bronzo, Vieux Moulin, Table des Marchands, Mané Kerioned, Mané Lud, Mané Rutual – Cassen 2011). In Gavrinis, a last objective is to explore engravings' overlaps in order to recompose the chronological order of execution of the signs on each stone, and to investigate the semiotic relationships between groups of motifs on adjoining stones inside the tomb.

3. Methodological choices

The principle of combining photographic and 3D laser techniques to record prehistoric rock art is not new (e.g. Pinçon, Geneste 2010; Carrera Ramírez 2011; Domingo *et al.* 2013). However, the application of this principle implies very different sets of methodological choices according to the context in which the art is found (cave, rock shelter, megalith, etc.), the geology of the rock surface and the nature of the art itself (painting, incision, carving, sculpture, etc.). A significant challenge in recording Gavrinis' art and architecture was to build new methodological processes specifically designed to the particularities of this Neolithic site, such as the morphological type of the engravings (hollowed pecked lines), their age (6000 years) and conservation state, the unique complexity of the engraved compositions and their exceptional distribution all over the walls of the tomb, the exiguity and lack of backspace for recording equipment, or the presence of engravings on obscured parts of the stones.

The methodology presented here combines laser scanning for the recording of art, stones and architecture, and several types of enhancement techniques of 3D points cloud and photographs for the identification of both content and sequence of the engravings. As it will be argued in this article, these techniques are not used in a separate and additive way but rather in a complementarity perspective: their results complement each other and can be combined in order to create a final, comprehensive and accurate digital model of the decorated tomb.

3.1. Lasergrammetric recording and post-processing of points clouds

A review of the experiences of three-dimensional recordings of megalithic monuments in Europe since the 1980s (Cassen *et al.* 2013) shows the difficulties met by archaeologists in using and processing spatial geometry data. Projects are often limited to the description by archaeologists of immediate dramatic 3D images of sites that were produced by engineers. Though the potential for further uses of the 3D data for architectural analyses and reconstruction, or representation of megalithic art, is commonly cited, this potential is not applied in most cases as archaeologists usually cannot manage and process such data.

As an exception, the international reputation of a site like Stonehenge made it possible successive remarkable experiences with increasing accuracy and quality of representation (Goskar et al. 2003; Abbott, Anderson-Whymark 2012). Also notable are key scientific objectives such as measurement of erosion process (Field, Pearson 2010) whose study is primordial in the field of rock art studies. The presence of paint on the walls of megalithic monuments brings similar issues and recent programs at the Neolithic passage tomb of Dombate in Spain shows how a combination of lasergrammetric, photogrammetric and orthophotographic techniques has the potential to inventory and localize the agents that threaten the paintings and carvings on the walls (Carrera Ramírez 2011). However, our own experience of lasergrammetry applied to the recording of neolithic stele and tombs (Cassen, Merheb 2005) revealed how, as archaeologists, we are lacking a mastering of post-acquisition processes in order to advance in the identification and representation of the Breton engraved signs. As a consequence, we think that a more permanent dialogue between archaeologists and specialists of 3D programs applied to architecture is a mandatory prerequisite for the achievement of comprehensive 3D recordings of prehistoric sites, as the collaborative work between archaeologists and architects presented is this paper wants to illustrate it.

Therefore, we first considered lasergrammetry as the best technical option for Gavrinis in order to record both the volumes of the architectural structure and the details of the carvings on the wall surface. Two different equipments were complementarily used to record the site in order to cover the different scales, from details of the engravings to the whole cairn.

- A Leica Geosystems C10 laser scanner was used for the outer surfaces of the cairn and the whole megalithic structure inside it, with a resolution of 1 cm to 1 mm for the outer spaces, and of 1 mm for the inner spaces. Six stations were needed all around the cairn and on top of it in order to cover almost entirely the monument. Eight stations were realised inside the cairn, in the megalithic passage and chamber, as well as in the modern room built over the large chamber capstone whose upper face is engraved. The relative position of each station was recorded using markers placed outside the cairn.

- A Nikon Krypton K610 handheld scanner was used for a more detailed recording of each decorated stone, with a 1 mm resolution for the passage and chamber orthostats, and 0,5 mm for the upper face of the engraved capstone. This represents a total of 12,475,898 points for the chamber orthostats, 15,262,464 for the orthostats on the left side of the passage, 15,989,798 for those on the right side, 28,671,111 for the ceiling and 2,766,463 for the paved floor.

All scans were geographically referenced (Lambert and IGN 69 reference systems) and integrated into a single spatial model. Data (point clouds) were saved in *.xyz and *.stl (meshed) formats.

More challenging and experimental was the post-acquisition processing of the data. Taking into account essential parameters such as processing time, data volume, mesh repartition and exportation, and the enhancement of the engravings, the reverse engineering software *Geomatic* (*Studio* version) proved to be the most effective. Let us take orthostat L6 as a case study. When opening L6 point clouds in the software, one notices that the default meshing of the data automatically created (Fig. 3, A) is not really satisfactory. A bitmap capture of this view was consequently created and processed in *Adobe Photoshop* (saturation/level/curves) in order to have a better rendering of the natural relief of the orthostat.

In order to make visible the form and extent of the engravings, three types of visual documents were created: a deviation map (*Geomagic*), a bitmap image of the deviation map combining HD and tensed meshing (*Adobe Photoshop*), and a vectorised version of the latter (*Adobe Illustrator*). All images were given the same orthogonal point of view in order to compare their results and to combine them.

The first document is called a deviation map (Fig. 4). It allows to assess the distances between a high definition (HD) meshing of the points cloud, which contains very detailed information on the surface, and a smoothed (i.e. homogenised) meshing.

The deviation map consists in a colour code ranging from red (on areas where the smoothed surface is located above the HD surface), to dark blue (where the smoothed surfaced is below the HD surface), and green (where smoothed and HD surfaces are very close to each other). This results in a colour gradient, which represents the distances in millimetres from the smoothed to the high definition surface. The original application of this technique to Neolithic art is that the colour code makes it possible to show the engravings in yellow, and sometimes in red for the most pronounced reliefs.

The second document is a bitmap capture of a combined view of HD and tensed meshing in *Geomagic*, which is subsequently converted in greyscale in *Adobe Photoshop*. Yellows and reds (i.e. engravings) are converted into white while all the rest of the stone surface is converted into black (Fig. 5, A).

The third document consists in the vectorised version of the second document, created in *Adobe Illustrator* (Object/Live Trace/Make and Expand). This permits to automatically create vector line drawings of the outer contours of the pecked motifs highlighted in the second document (Fig. 5, B). Vectorised versions made with different settings can be superimposed and be given different colours in order to give further details on pecked contours (see detail in Fig. 5). The resulting file is regarded more as a pre-recording or pre-analysis of the art. It is used as an initial drawing basis whose details can be transformed and adapted as further recording investigations are made with other techniques, and from which a final drawing of the engravings is eventually produced.

3.2. Photography with oblique lights

The second recording technique used in Gavrinis is a 2D photographic technique, which allows to identify very faint engravings thanks to a series of various oblique lightings and computer processing of photographs. A detailed description of this method, which has been used in several megalithic art sites in northwest Europe, has been published elsewhere (Boujot *et al.* 2000; Cassen, Robin 2010). The following section will focus on its application at Gavrinis and its complex engraved compositions.

Keeping orthostat L6 as a case study, 98 photographs[1] were taken from a same station and with oblique lights from different sources and angles in order to make visible the various engravings all

[1] The equipment used is as follows: Camera body: Nikon D5000; Lens: Nikon 10.5mm f/2.8G ED DX Fisheye-Nikkor; Remote control; Kaiser (StarCluster) LED torch, day light (5600°K; 500 lux); A4 Wacom (Intuos) drawing tablet. Photographic settings: ISO 200; RAW format; Aperture at 16. The difficult shooting conditions inside the tomb (maximum distance less than one meter for photographing stones of 0.70 to 1.78 m wide and 1.44 to 1.75 high) imposes the use of a very wide angle lens (fisheye). Correction of the deformations resulting from the use of such a lens is now widely available thanks to various softwares such as *Nikon Capture*, *Adobe Photoshop* or *Image Trends (Hemi)*.

over the stone surface. The edges of the pecked lines revealed by light contrasts on the photographs were subsequently drawn manually with a digital tablet in *Adobe Illustrator*, using vector lines with short offset barbules showing the inside of the pecked line (Fig. 6, top). The different drawings were then grouped together in a single file that gives a first overall result of the process (Fig. 6, middle).

The final synthetic drawing (Fig. 6, bottom), which has slight focal distortions due to the camera, was eventually distorted in order to refit with the map of the stone made after the 3D points cloud. This can be made either in *Adobe Illustrator* (Free Transform tool) or *Adobe Photoshop* (Edit/Transform/Distort) using the bounding box handle of the selected part of the image.

A limit of the oblique light technique appears when distance is missing between the light source and the engraved stones, which may happen in a megalithic tomb like Gavrinis. It is not easy to record the totality of engravings that cover the entire surface of orthostats, especially those located towards the edge of the stone or towards the ground, as the light is obscured by adjoining orthostats and capstones. The light, consequently placed too close to the engraved areas, makes them overexposed in the photographs, and opposed directions of light are not possible. Such problems, not often encountered so far in Brittany where stones are rarely entirely engraved, show the limitations of the recording technique in confined spaces (see missing parts of the recording in Fig. 6, especially on the right edge of the stone).

3.3. Comparing techniques

In order to assess the advantages and limitations of the different techniques described above, a comparative study of four recording results (lettered A to D), focusing on the top part of orthostat L6, was realised.

A. The first recording discussed here-is the drawing (the best in the corpus) executed by E. Shee Twohig (1981) with direct tracing on cellophane and polyethylene sheets (Fig. 7).

B. The second recording is the synthesis resulting from the oblique light technique (Fig. 6, bottom). The result presented here is a minimum recording, as the usual complete process implies additional photographic recordings focusing on problematic areas where details of the engravings are missing.

C. The points cloud obtained by lasergrammetry can be processed in different softwares in order to produce two types of recordings of the engravings:

- C1: the first one is produced in the free software *Meshlab* and uses virtual oblique lighting on the 3D model in a similar way as for the photographic technique (Fig. 8). Despite several limitations (meshing errors and exportation failures for heavy files, limited perspective view), *Meshlab*, contrary to *Geomatic*, offers precise settings for the positioning of lighting (Render/Shader/Lattice/Light position). This permits to detect engravings and to draw them manually. A total of 36 views were drawn to produce a synthetic recording (Fig. 9).

- C2: the second recording is made in *Geomatic* and uses the principle of the deviation map. As described above, the deviation map makes clearly visible the contours of the pecked motifs, which were subsequently drawn with a digital tablet in *Adobe Illustrator* (Fig. 10).

We can now examine the convergences and differences between the four techniques. To do so we will compare the results obtained for four selected motifs located on the top half of orthostat L6, (Fig. 11).

At first glance, the recordings seem all very similar, hence confirming the remarkable character of the recording work executed by E. Shee Twohig. However, a few comments about details in the carvings in all sectors (a, b, c, d) need to be made. The conclusions presented below result from thorough and contradictory examinations, and on-site cross verifications on the original engravings.

- Sector a: in three areas (indicated by arrows in Fig. 11), carvings recorded by E. Shee Twohig were not recorded by the other techniques; these were finally recognised as natural features of the rock. Similarly, the recording made from the deviation map in *Geomatic* has automatically produced an additional 'engraving' which proved to be an artefacts of the device.

- Sector b: the photographic recording has clear limitations for the carvings at the edge of the stone where several pecked lines were not recorded. Fig. 6, however, shows that the technique was able to recognise the lower edges of these pecked lines but failed in identifying their top edges, an opposed oblique light being impossible in this area.

- Sector c: the top end of the two signs on the left (interpreted as two arrows associated with the adjoining bow) were not accurately recorded by the direct tracing technique (Shee Twohig), whereas the three other techniques perfectly identified them as transverse arrowheads, a typical lithic technology of Neolithic Western France (Guyodo 2005).

- Sector d: here *Geomatic* failed to identify a very faded vertical pecked line less than 0.5 mm deep, and the drawing by Shee Twohig did not record the whole of this reticulated motif. Only a combination of the recordings using real or virtual oblique lights (Fig. 11, d1) makes it possible to reconstruct the totality of the engraved motif.

To sum up, all these techniques have different strengths and limitations, and the better way to use them is to combine their results to create a single recording product. Photography and points cloud should therefore be used to produce complementary recordings of Neolithic pecked stones within a single methodological procedure. We should also point out that, in this multiple methodology, a large number of visible details from the contour of an engraved line does not mean a more accurate recording: if the deviation map technique allows to make a much more detailed drawing than the oblique light technique (Fig. 12), the later brings more information and is more pertinent because its principle lays in a superimposition and synthesis of several drawings.

Let us see now a significant achievement of these techniques, which is the reconstruction of the chronological sequence of the execution of the signs.

4. The chronological sequence of the engravings

The two reference documents here are, on one side, the deviation map, on which overlapping engraved lines (with a latter line cross-cutting an earlier one) are already visible, and, on the other side, the vector drawing made from the deviation map. An inventory of intersecting engravings on L6 and an examination of the corresponding crossing or contact points allow to infer the chronological sequence of the engravings.

Four different situations were recognised:

1- *Cross-cutting* of engraved lines: the edges of the latter line are marked inside the hollow of the earlier one (Fig. 13, 1).

2- *Removing of surface material*, when a latter sign overlaps on earlier one (Fig. 13, 2).

3- The *negative track* of an earlier engraved line which, even very faded, affects the form of a latter engraving at their crossing points (Fig. 13, 3).

4- Engraved line *avoiding* another one, which must be interpreted as the result of two distinct phases (Fig. 13, 4). Though this last case is not as demonstrative as the previous ones, and should be used moderately, it can be taken into for the reconstruction of the chronological sequence of the engraved composition.

Situations 2 and 3 cannot be identified by lasergrammetric recording, which uses a resolution of 0,5 mm, nor by the deviation map created in *Geomagic*, or by virtual oblique lights created in *Meshlab*. Only photographic recording with real oblique lights has the potential to identify such features, for example in situation 3 (Fig. 13, 3) whose recording required no less than 41 photographs.

From these contact situations, chronological relationships can then be established between motifs or groups of associated signs (less often between individual signs). An order of execution can be deduced in which several entities, termed as semiotic, are placed in relation to each other. For example, the earliest engravings (phase B in Fig. 14) consist in rectilinear signs that were executed from the right to the left. Their arrangement divides the surface of the stone, using natural features of the rock surface (Fig. 14, A). During the subsequent phase C, all figurative motifs (bow, arrows, polished axe heads) were executed, here again from the right to the left (Fig. 14, C). The following phases D to G correspond to the execution of the abstract geometric motifs (Fig. 14, D-G).

From the homogeneous technical signature of the engravings it seems clear that the whole art executed on L6 is a single project and event. Consequently, the sequence detailed above should be understood as a short-term chronology (or “chronography”) showing the successive steps in the execution of the engraving project. Distinct stylistic periods (Shee Twohig 1981, 64; O’Sullivan 1997) have not been identified for this particular stone. The results of this chronography can be efficiently synthesised into a matrix showing the succession of the different semiotic entities and the sequence of the main phases (Fig. 14, bottom right), as a Harris matrix does for archaeological sites' stratigraphy[2].

5. Recording faint engravings on hard stones: limitations of inframillimetric techniques and unexpected solutions by colour enhancement techniques

Orthostat R11 is a hard sandstone, a material rarely used at Gavrinis where most of the stones in the megalithic structure are grained rocks of granite and gneiss type. The engravings on R11 are consequently much fainter than the ones made on the other stones of the tombs, and identifying them proved to be a technical issue. While the art of all other engraved orthostats was immediately visible on the monitor screen during the scanning process, without any particular light arrangements, only a very few engravings shown in E. Shee Twohig's drawing were appearing on

[2] See Loubster (1997) and Marretta *et al.* (2011) for a use of Harris matrix showing the superimposition sequence of rock paintings and incisions.

the points cloud.

5.1. The results of the lasergrammetric and oblique light techniques

Naked-eye perception of the engravings on R11 depends on the hygrometry rate inside the monument. During dry weather with easterly or northerly wind, some engravings are visible on the top and bottom part of the stone (see photograph A in Fig. 15), corresponding to the most clearly recorded engravings in Shee Twohig's drawing of the stone (Fig. 15, B). During humid weather and prevailing wind from the Ocean, all the engravings are virtually invisible to the naked eye.

Not surprisingly, the deviation map technique completely failed in identifying the engravings (Fig. 15, C). This is due to the very faint depth of the pecked marks (*c*. 0.1 mm), inferior to the maximum resolution of the scanner (0.5 mm) which, before being tested on that particular case, was considered as accurate enough. Even engravings visible with the naked eye were not recorded by the scanner.

We consequently decided to use the oblique light photographic technique. A series of 267 photographs was realised, an exceptional number which demonstrates in itself all the difficulties encountered in making visible the engraved reliefs with the oblique lights. A synthetical drawing was nevertheless completed (Fig. 15, D). Even if new engravings were identified in the bottom and left part of the stone, the whole process turned out to be very long and difficult, and even uncertain at some points.

5.2. Colour detection using *DStretch*

As noted above, the nature of the engravings on R11 is quite different from the rest of the tomb and consist not in hollowed pecked lines but rather in a superficial crushing of the rock surface (Fig. 16, A and B), resulting in lightness (light on dark) and texture (matt and coarse on the gloss and smooth surface of the weathered sandstone) contrasts. Based on these particular visual characteristics, an experience was attempted using a colour detection technique.

The software used is *ImageJ* (Abramoff *et al.* 2004), a Java-based program in the public domain. Besides medical imagery, its original field of application, it is now routinely used for the recording of painted rock art (Gunn *et al.* 2010) with the plug-in *DStretch* (Harman 2008, version 7.1 ; http://www.dstretch.com), whose principle is to detect and enhance colour differences. It is quite unconventional to use the technique to identify faint peck-marks instead of pigments, but the result for orthostat R11 at Gavrinis was immediate and striking (Fig. 16, C).

Thirteen photographs were processed in order to obtain complementary information and a good restitution of the engraved surface. The carvings made visible on the photographs were drawn separately in *Adobe Illustrator*, and then grouped together in order to produce a final synthesis of the recording process, which shows much more elements and details than in previous recordings (Fig. 16, D).

6. Conclusions

Preliminarily to the reinterpretation work of the symbolic representations in Gavrinis passage tomb, which are one of the most famous Neolithic art in Western Europe, the creation of a new corpus of the engravings was considered to be a priority. Not only have the signs to be identified on the surface of the stones, but they also have to be understood in their architectural context (the funerary chamber, the access passage, the covering cairn) and in the volume of the individual stones (the orthostats making the walls). The present article describes recording techniques for the engravings, which is only one component of this multiscalar approach to the monument. The ultimate objective is to find the internal dynamics within these engraved compositions as well as possible hierarchical relationships between the signs.

The reference document for each decorated orthostat is a georeferenced points cloud generated by lasergrammetry with a millimetric resolution. One technical challenge is to find the appropriate balance between recording accuracy and a reasonable size of the digital files making feasible their processing and operating. Each file is about 250 Mo for one orthostat ranging from 0.70 to 1.80 width and 1.40 to 1.80 heigth, while engravings are generally 2 to 3 mm deep.

Taking the complex engravings of orthostat L6 as a case-study, we have described the innovative archaeological application of the principle of the deviation map. The image produced with this technique highlights the engravings as hollowed lines and serves as a guide for the manual vector drawing of the art using a drawing tablet. In order to compare the results of the deviation map technique and of the photographic and oblique lights technique, the latter method was applied to orthostat L6 for which 98 photographs were taken. The limitations of this method is obvious on the edges of the stones where oblique lights are made impossible or obscured by adjoining elements such as the ground floor, the ceiling, or protruding orthostats, forcing the light source to be placed close to the stone and to consequently overexpose some areas. This limitation is problematic at Gavrinis but not in other megalithic art contexts in 5th and 4th millenium B.C. Western France, where engravings are usually not made all over the surface of the stones.

Moreover, the photographs and oblique light technique proved to be more efficient than lasergrammetric technique for the identification of anteriority/posteriority relationships between the signs. Despite the high resolution (0.5 mm) of the laser scanner, the resulting 3D points cloud could not highlight such relationships outside the deepest cross-cutting lines, and virtual oblique lights on the model could not answer all questions on the diachrony of the engravings, particularly for the most eroded ones. Only the processing of photographs taken with oblique lights gave enough detailed information about the engravings and their chronography, making it a necessary and complementary technique to lasergrammetry.

Neolithic engraved art in Brittany is often difficult to record in a accurate and comprehensive way, however two out of the 25 decorated orthostats in Gavrinis are even more difficult to record because of the sandstone material on which art is made. Recent experimentations conducted by Marie Vourc'h and Cyrille Chaigneau at Gavrinis have shown that deep pecked engravings (2 to 3 mm deep) are easily and rapidly (1 cm by minute) executed on granite, which is a grained rock. Sandstone, however, with its agglomerated quartz grains, opposed much more resistance to pecking, which was not able to produce similar engravings as on granite. On that rock, engraved lines can only be very faint (0.1 mm) and are only visible from the colour difference between natural and pecked surfaces. As a consequence, recording techniques based on lasergrammetry and photographs with oblique lights failed in discerning engraved figures that are yet visible with the naked eye during good hygrometric conditions. From the idea that the visibility of such engravings during the Neolithic was based on lightness contrasts between the pecked surfaces (light colour, almost white) and the raw rock surface (weathered dark yellow colour), an experience has been conducted using a program for colour enhancement processing of photographs (*ImageJ*). The technique, working on colorspace, made it possible to recognize a large number of ancient engravings today invisible with the naked eye and finally to record nearly twice as many engravings as previously known.

The first lesson of this methodological research on Neolithic art documentation technique is that a comprehensive recording and representation of the engravings, from the decimetric scale of the stone reliefs to the inframillimetric scale of the pecking, cannot be achieved by any of these techniques if used separately. Only a combined use of lasergrammetric and photographic techniques can realize this objective. The second lesson is that an interpretative work on the signs engraved in

Neolithic tombs should not be based only on a simple static representation of the motifs but also on a detailed reconstruction of their spatio-temporal dynamics or chronography. The techniques described in this paper are particularly efficient in achieving such a reconstruction.

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Figures captions:

Fig. 1: Aerial view and location maps of the Neolithic cairn on Gavrinis island (Morbihan, France ; photograph: Sagemor).

Fig. 2: 3D elevations of Gavrinis cairn and walls (passage and chamber) from lasergrammetric survey. Panoramic view from the chamber and location of the two engraved slabs (R11 and L6) described in the text.

Fig. 3: Orthostat L6. On the left (A), view of the 3D model in *Geomagic*; on the right (B), same image after processing in *Adobe Photoshop* (shading by the normals).

Fig. 4: Deviation map of orthostat L6 as set on "440" in *Geomagic*.

Fig. 5: Orthostat L6. Conversion of the deviation map into a black and white image (A) and of this image into a vector file (B). Bottom: detail of superimposition of different vectorised files with each line colour corresponding to a different processing in the deviation map.

Fig. 6: Orthostat L6. Top: Example of photographs with oblique lights with corresponding vector drawing of the engravings. Middle: superimposition of all the vector drawings, resulting in a synthesis showing the contours of the engravings. Bottom: preliminary illustration of the recording results, showing groups of signs in different colours.

Fig. 7: Orthostat L6. 1981 drawing by Elizabeth Shee Twohig with frames showing areas discussed in fig. 10.

Fig. 8: Views of 3D model of orthostat L6 in *Meshlab*, using three different virtual light settings.

Fig. 9: Orthostat L6. From top to bottom: 3D model with virtual side oblique light as viewed in *Meshlab*; compilation of vector drawings made from 36 images of the 3D model with various oblique lights; same result with vector offset lines showing the contour and inside part of the motifs; graphic synthesis with preliminary colour distinction of groups of motifs.

Fig. 10: Orthostat L6. Example of a deviation map showing the contour of the engraved lines, and corresponding vector drawing.

Fig. 11: Comparison of the results from different recording techniques on four areas of orthostat L6. Techniques compared here are: direct tracing (Shee Twohig 1981), drawing from photographs and oblique lights (Photos), drawing from 3D model with virtual oblique lights (Meshlab), and drawing from deviation map (Geomagic). See fig. 6 for location of areas a, b, c, d on orthostat L6.

Fig. 12: Comparison of the drawing processes involved in the photographic technique (above) and the deviation map technique (below). The first technique is based on a combination of several contour drawings from which a final average drawing is produced, while the second technique results in only one single drawing.

Fig. 13: Left: four situations of contact between engraved lines, from which chronological sequence can be inferred: 1- cross-cutting engraved lines; 2- removing of surface material; 3- execution of a latter engraving affected by occurrence of a earlier one; 4- Engraved lines avoiding each other. Right: comparison of results obtained with the technique using photographs and oblique lights (top) and the technique using 3D model and virtual oblique lights in *Meshlab* (bottom).

Fig. 14: Orthostat L6. A: principal natural features of the stone; B-G: principal sequences in the execution of the engravings established from an examination of contact points between motifs; H: engravings not attributed to any particular sequence. Note that the earliest motif (B1) uses and continues a major line of relief of the stone (A1). Bottom right: chronographic matrix of the main phases of art execution on L6.

Fig. 15: Orthostat R11. A: Unprocessed photograph showing the very poor visibility of the engravings with the naked eye. C: failure of the deviation map technique in making visible the engravings. D: recording of the engravings with the photographs and oblique lights technique compared to A: recording by E. Shee Twohig (1981).

Fig. 16: Orthostat R11. A: close view of the engravings made by superficial pecking of the sandstone surface. B: same image processed in *ImageJ* (with *DStretch* plug-in). C: Global view of the stone processed in *ImageJ*. D: resulting synthesis drawing (with correction of the lens distortion).

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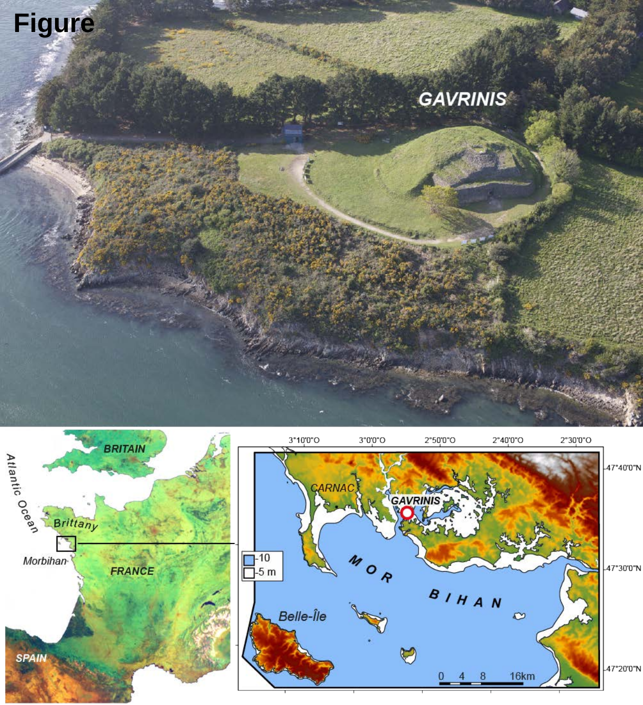
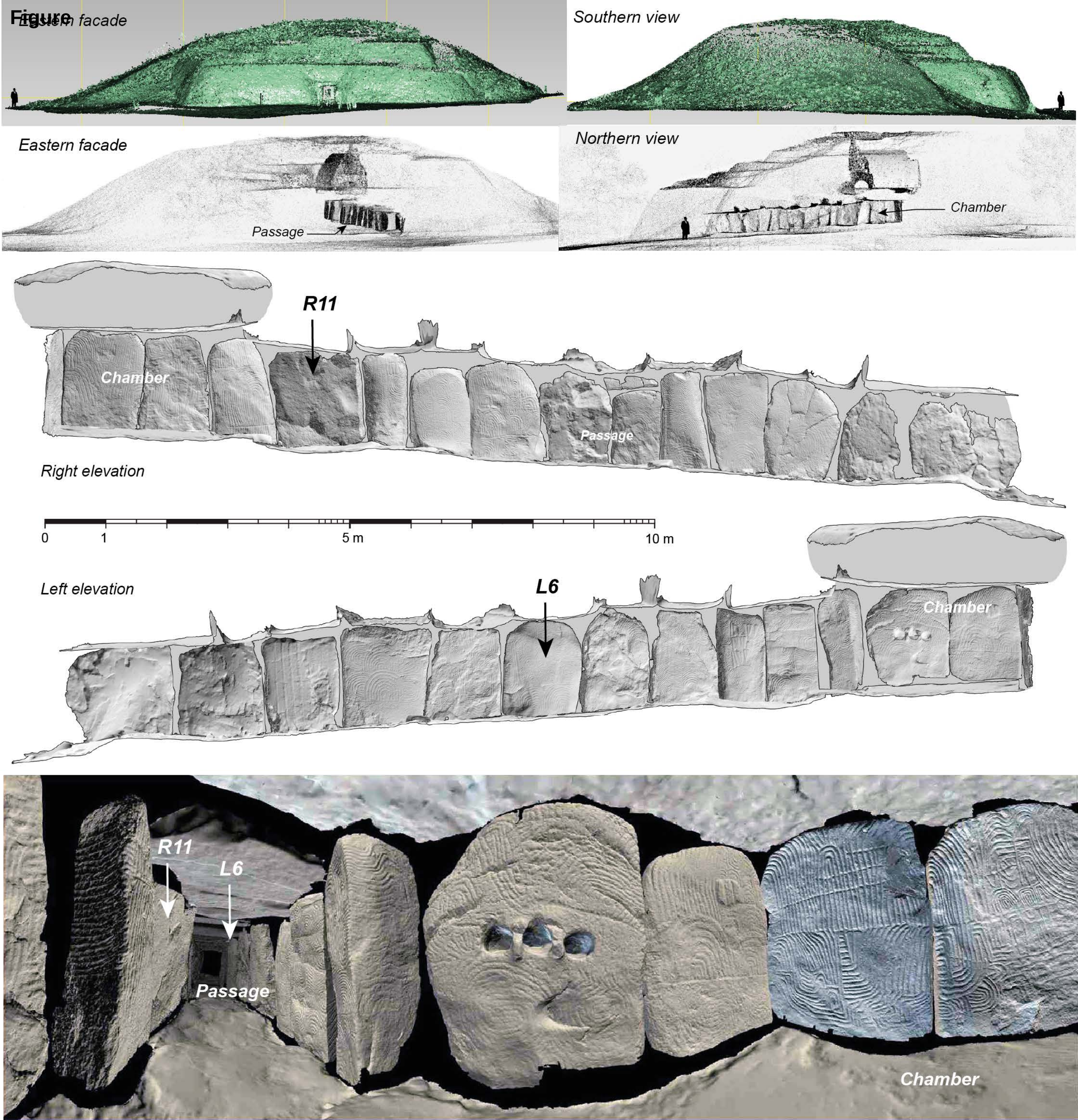
Figure

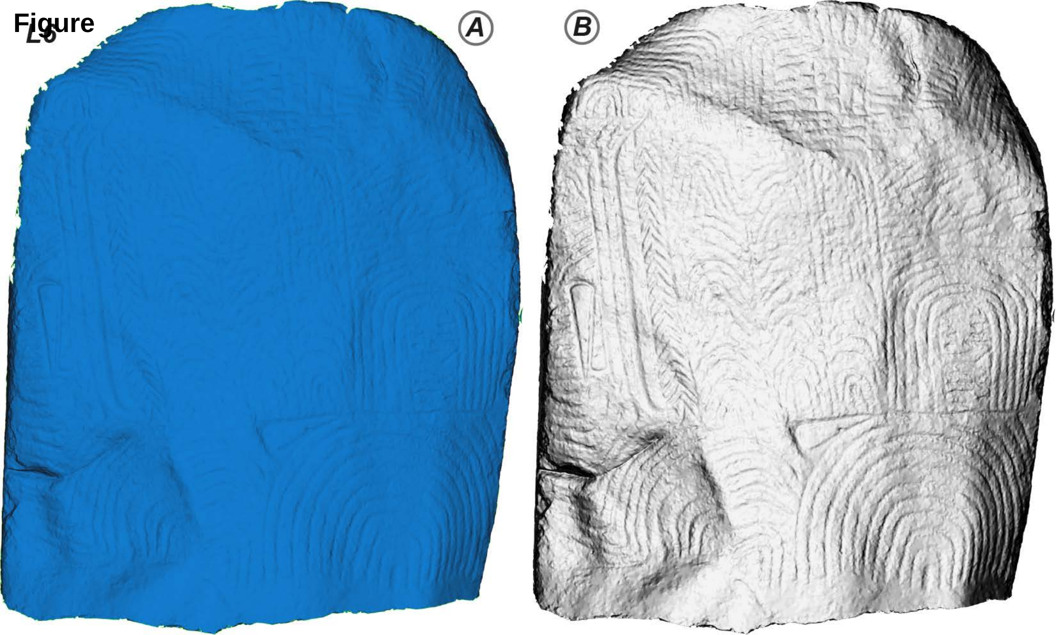

GAVRINIS
BRITAIN
Atlantic Ocean
Brittany
Morbihan
FRANCE
SPAIN
3°10'0"O
3°0'0"O
2°50'0"O
2°40'0"O
2°30'0"O
47°40'0"N
47°30'0"N
47°20'0"N
CARNAC
GAVRINIS
-10
-5 m
MOR
BIHAN
Belle-Île
0 4 8 16km

Figure



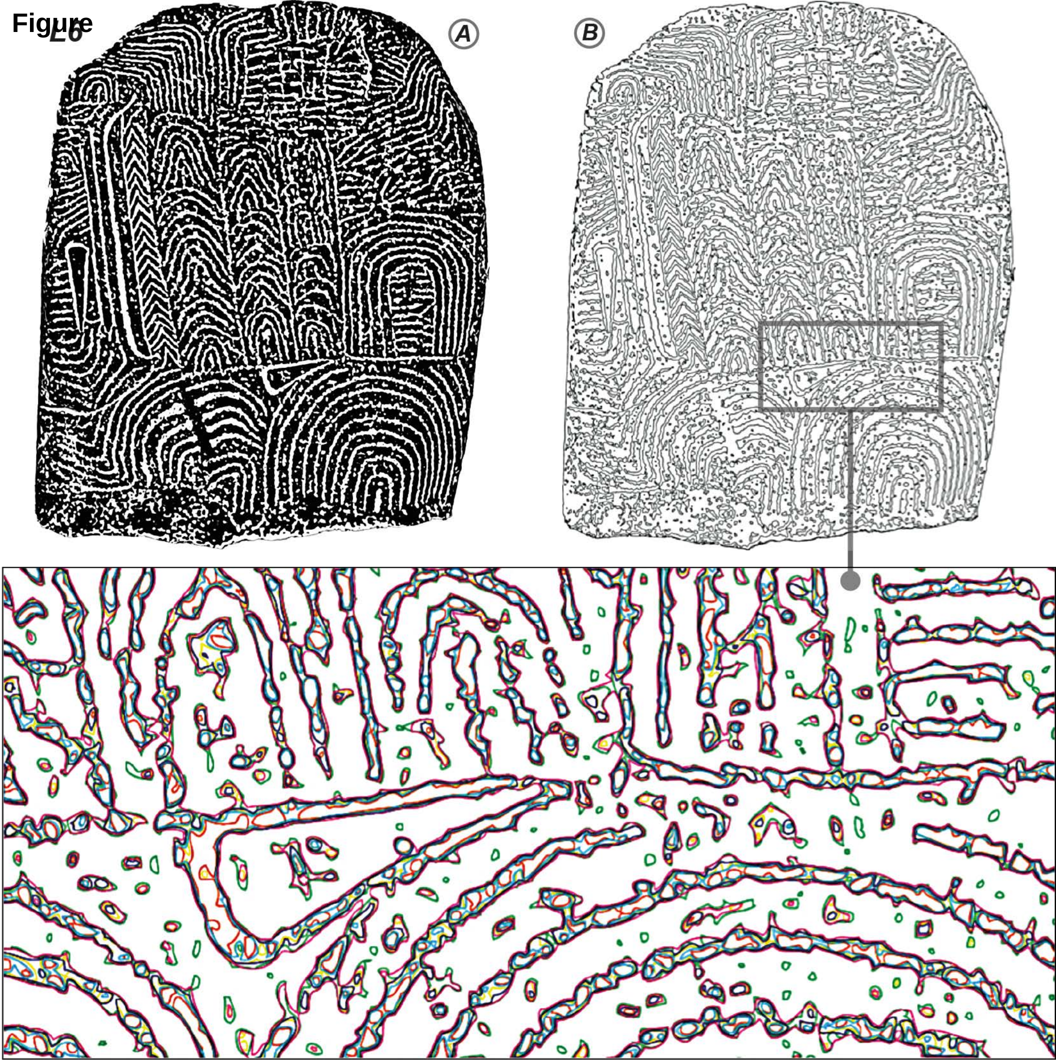
Eastern facade
Southern view
Eastern facade
Passage
Northern view
Chamber
R11
Chamber
Passage
Right elevation
0
1
5 m
10 m
Left elevation
L6
Chamber
R11
L6
Passage
Chamber

Figure

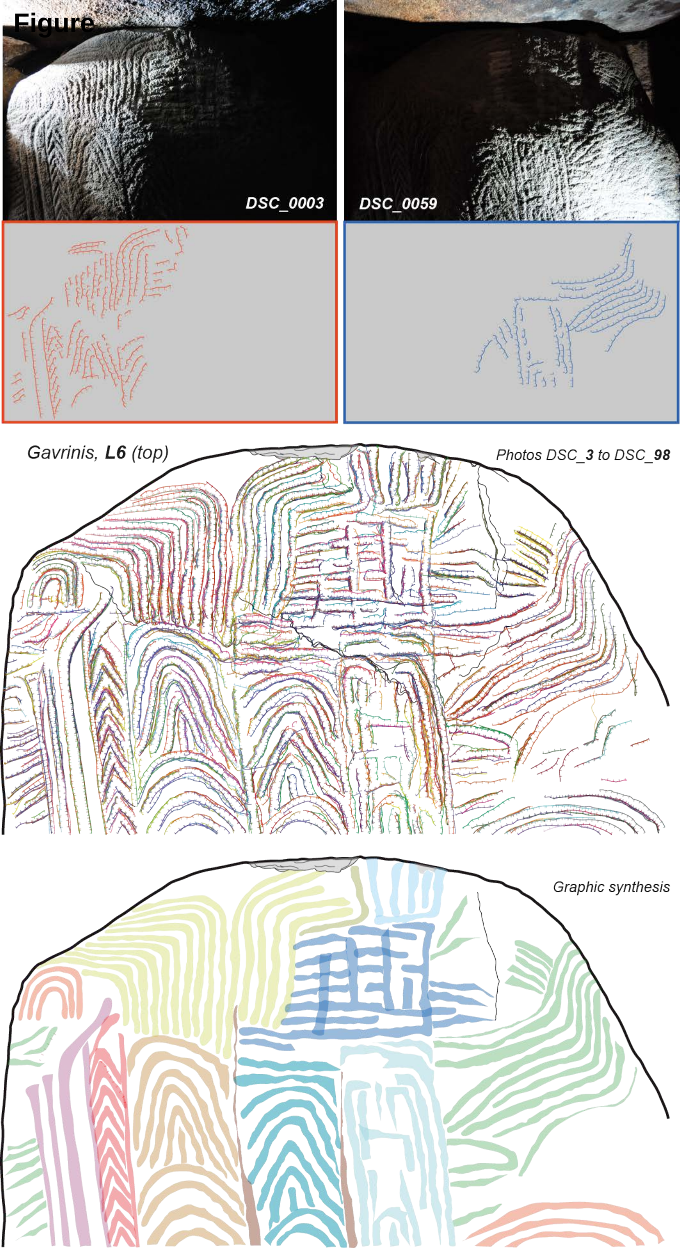


Figure

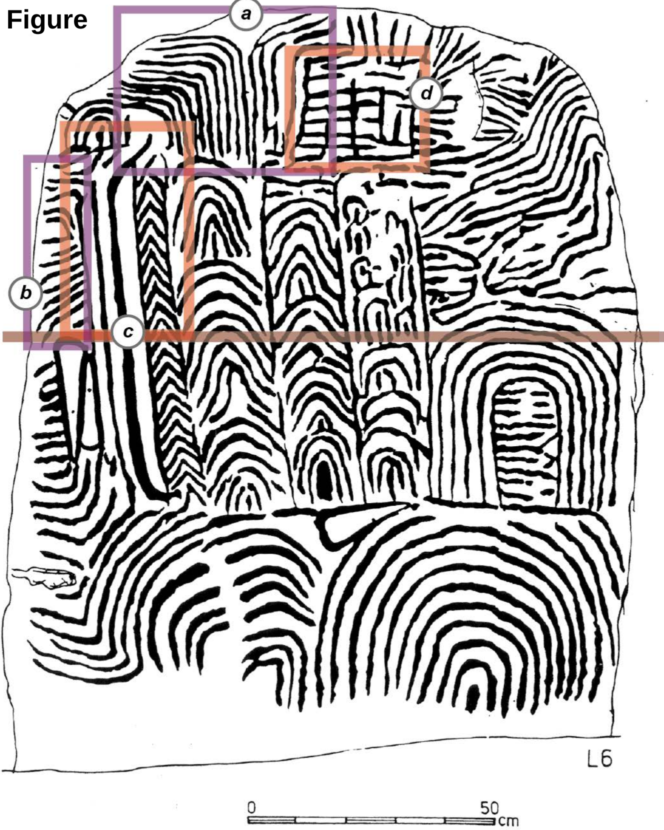
Figure



Figure


DSC_0003
DSC_0059
Gavrinis, L6 (top)
Photos DSC_3 to DSC_98
Graphic synthesis

Figure



Figure

(-2/ 1/ -1) (1/ 5/ 0) (5/ 0/ 0)

Figure

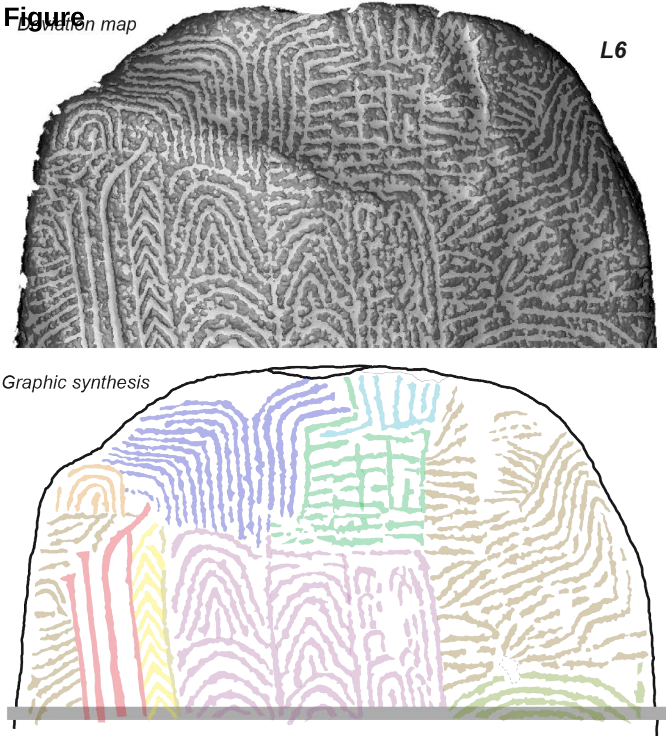
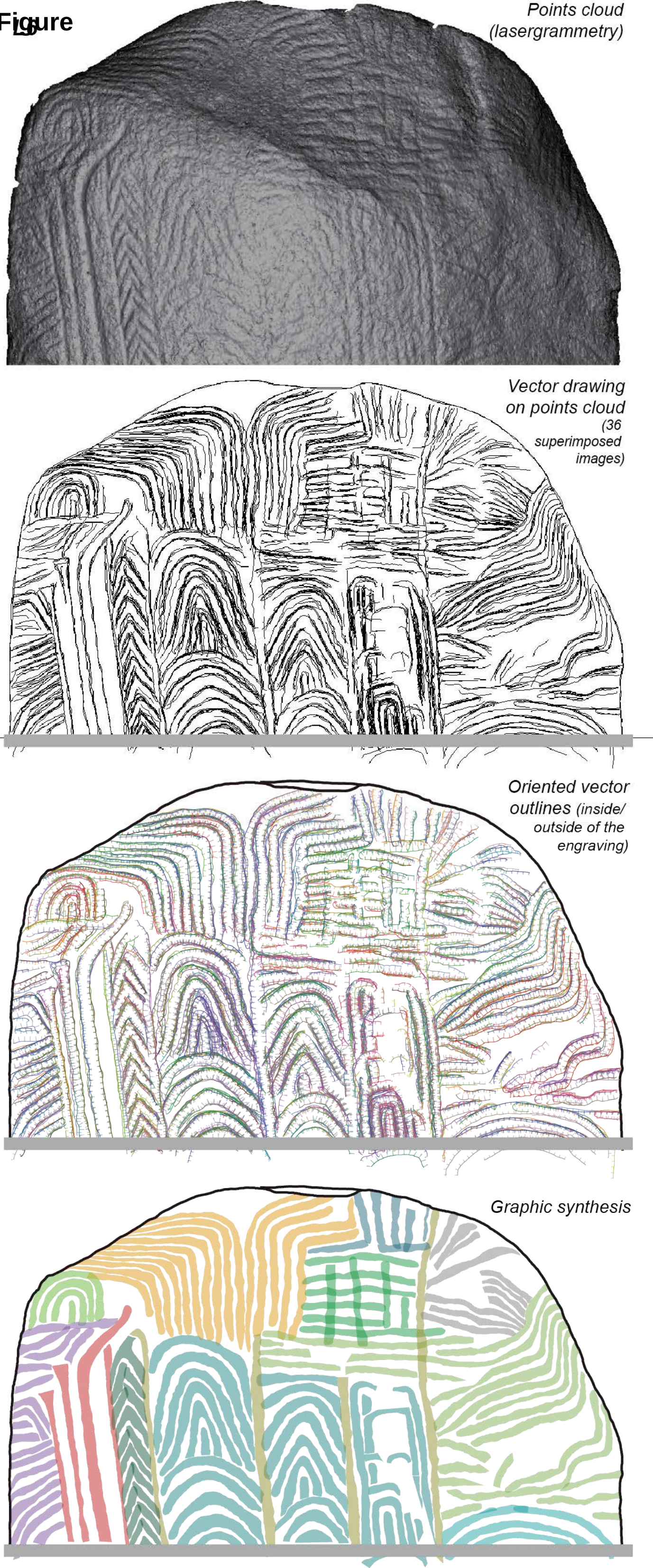
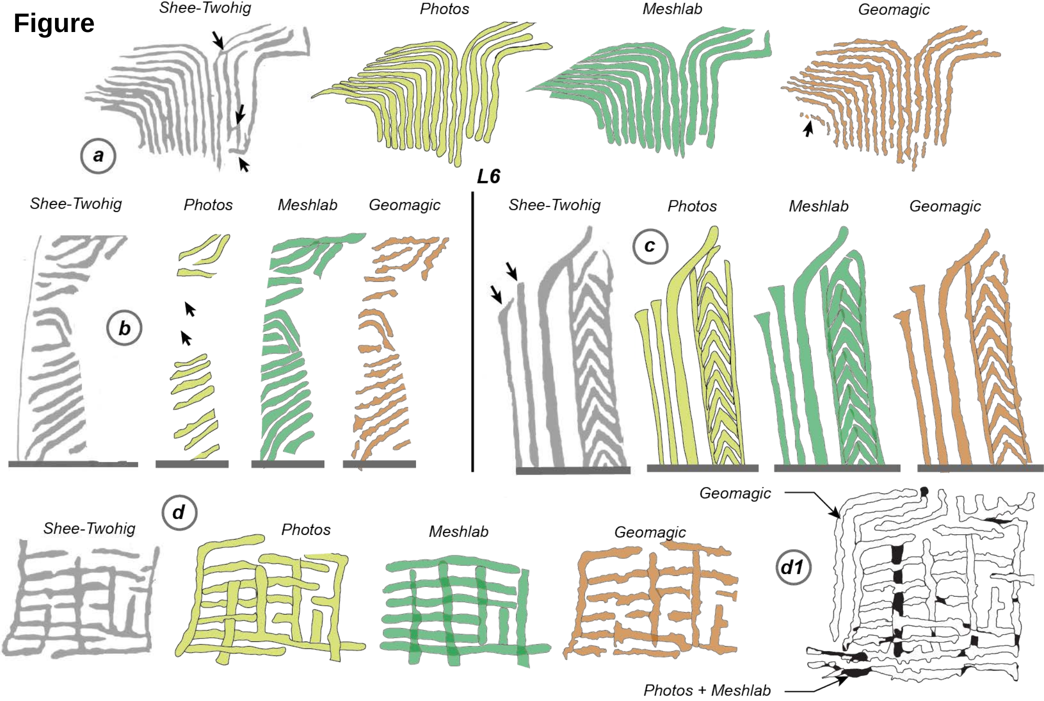


Figure 15



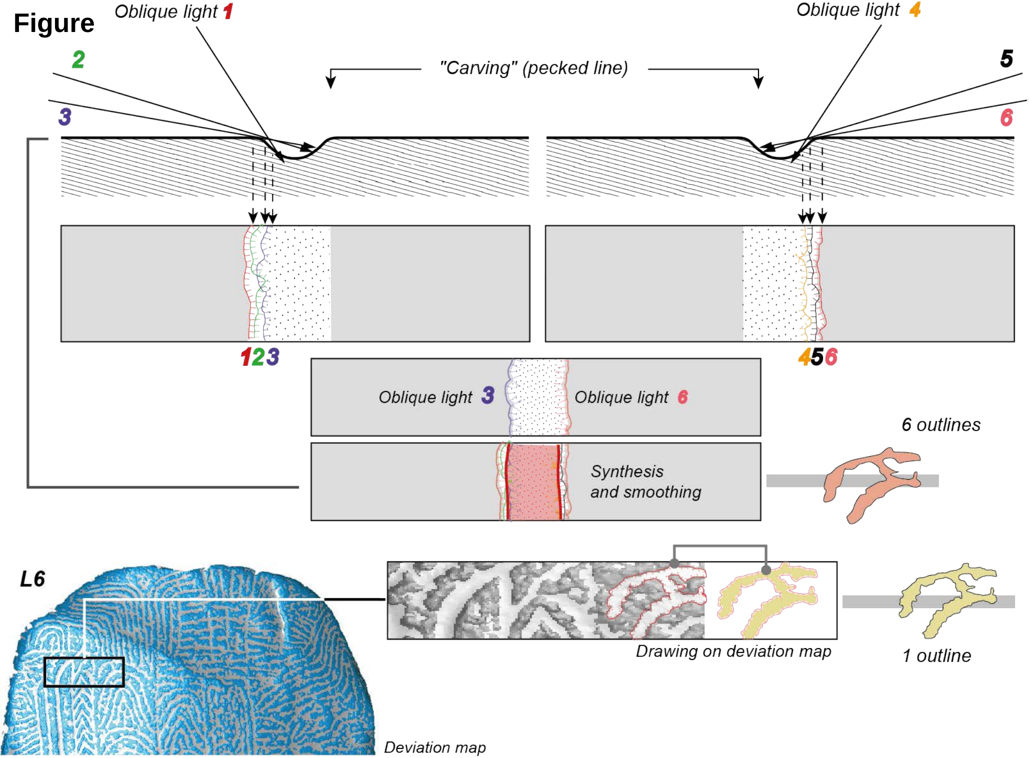
Points cloud
(lasergrammetry)
Vector drawing
on points cloud
(36
superimposed
images)
Oriented vector
outlines (inside/
outside of the
engraving)
Graphic synthesis

Figure



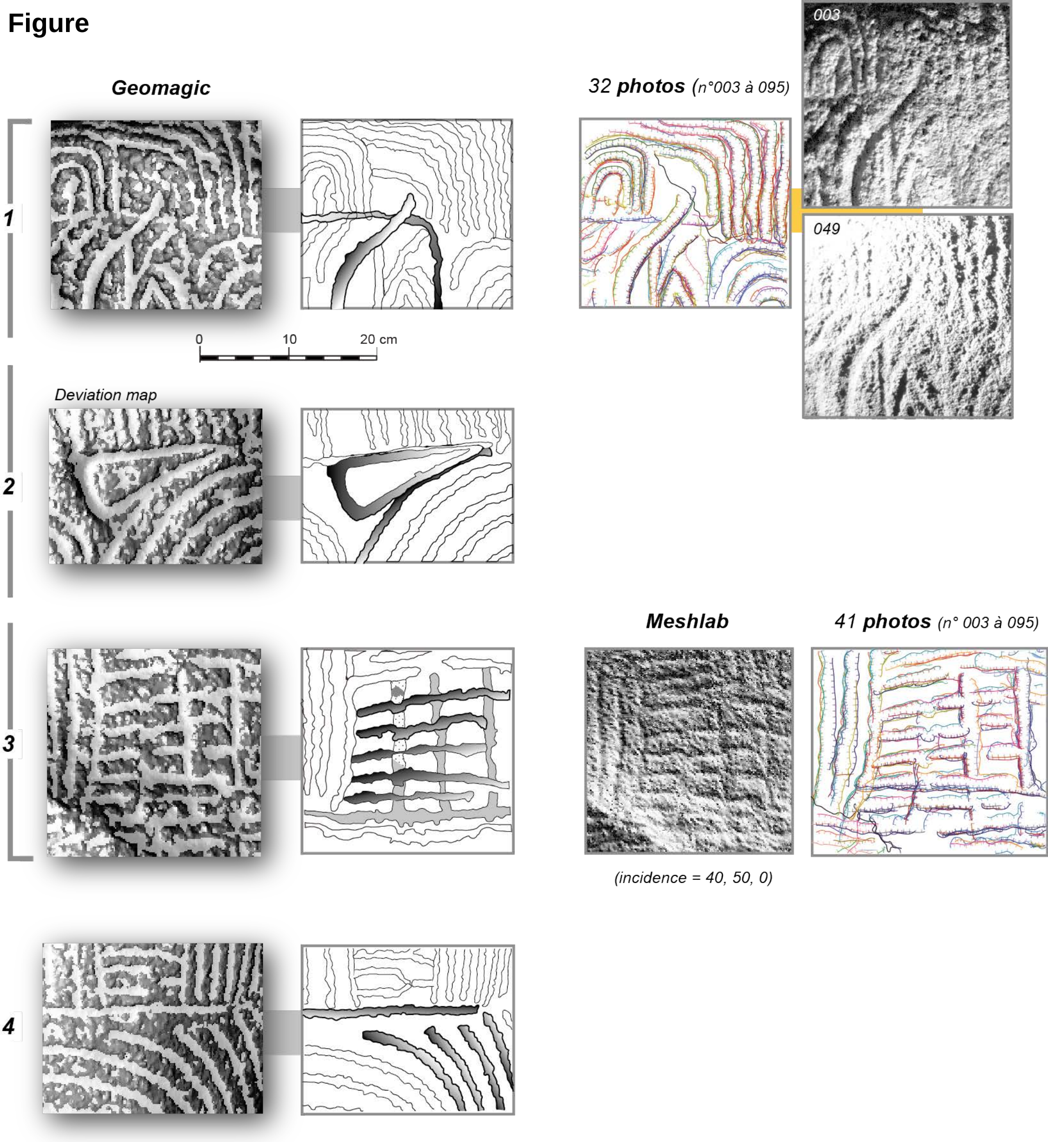
Shee-Twohig
Photos
Meshlab
Geomagic
a
L6
Shee-Twohig
Photos
Meshlab
Geomagic
b
Shee-Twohig
Photos
Meshlab
Geomagic
c
d
Shee-Twohig
Photos
Meshlab
Geomagic
Geomagic
d1
Photos + Meshlab

Figure

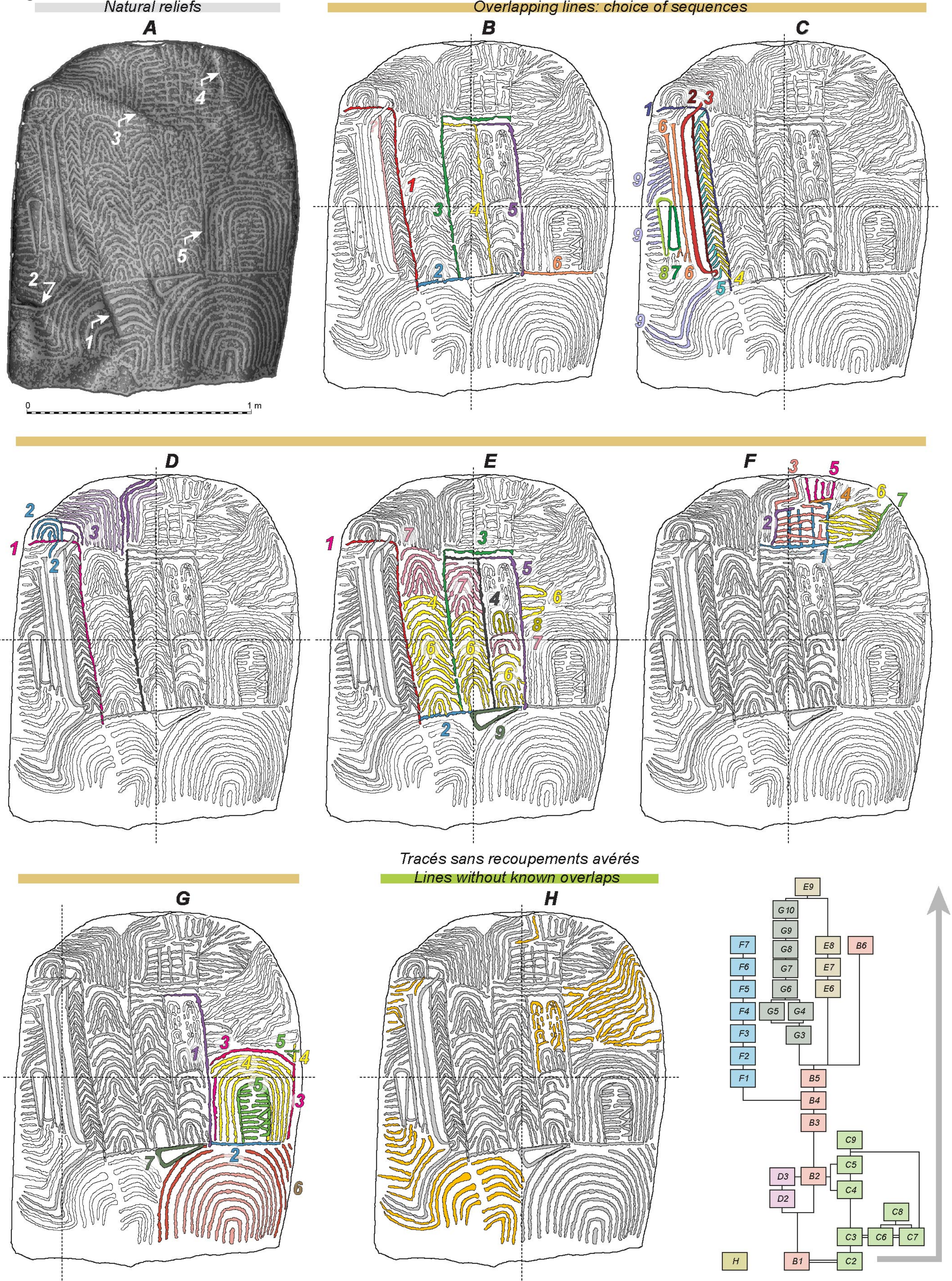


Oblique light 1
Oblique light 4
2
5
"Carving" (pecked line)
3
6
123
456
Oblique light 3
Oblique light 6
6 outlines
Synthesis
and smoothing
L6
Drawing on deviation map
1 outline
Deviation map

Figure

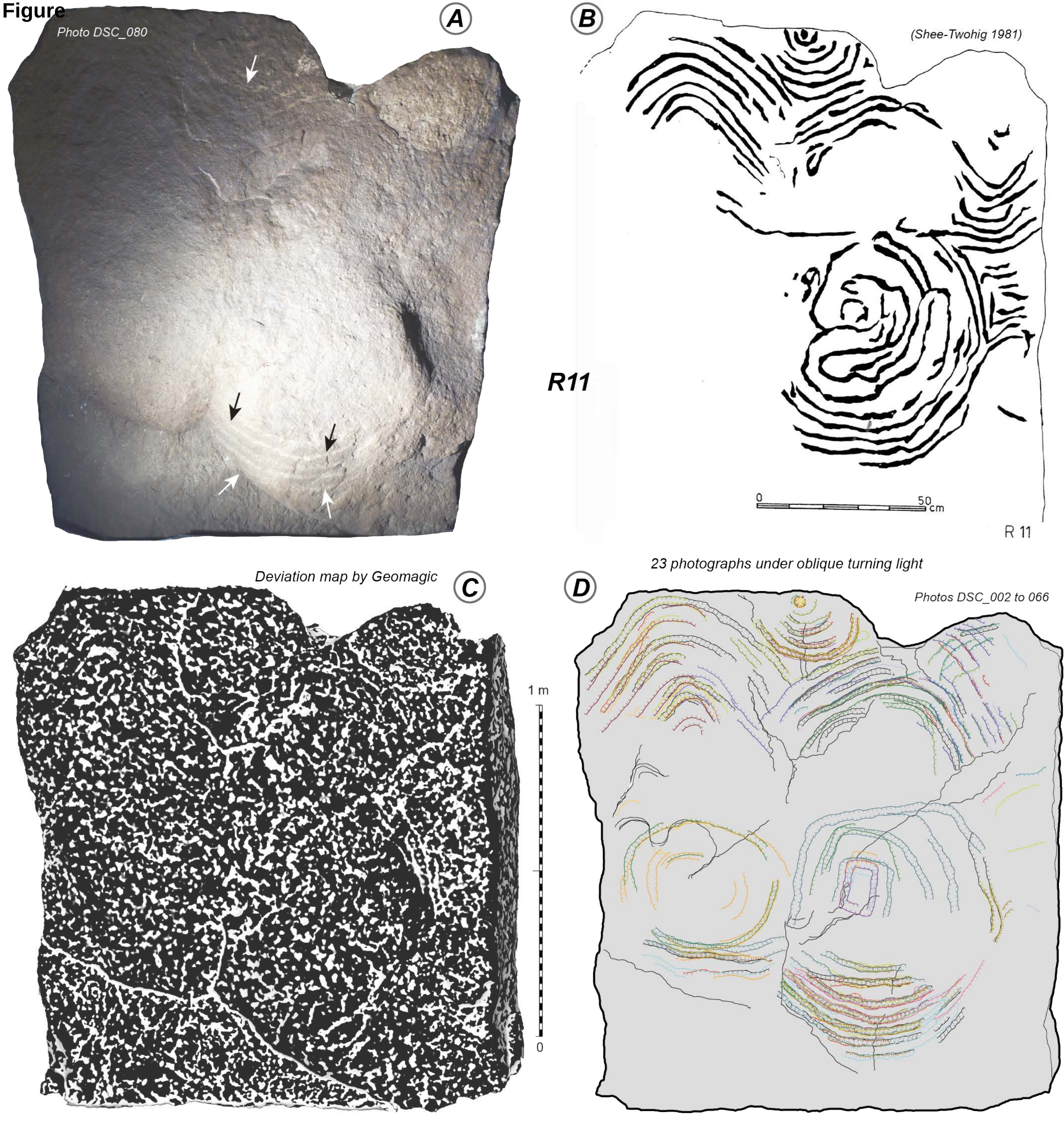

Geomagic
32 photos (n°003 à 095)
003
049
1
2
3
4
0
10
20 cm
Deviation map
Meshlab
41 photos (n° 003 à 095)
(incidence = 40, 50, 0)

Figure

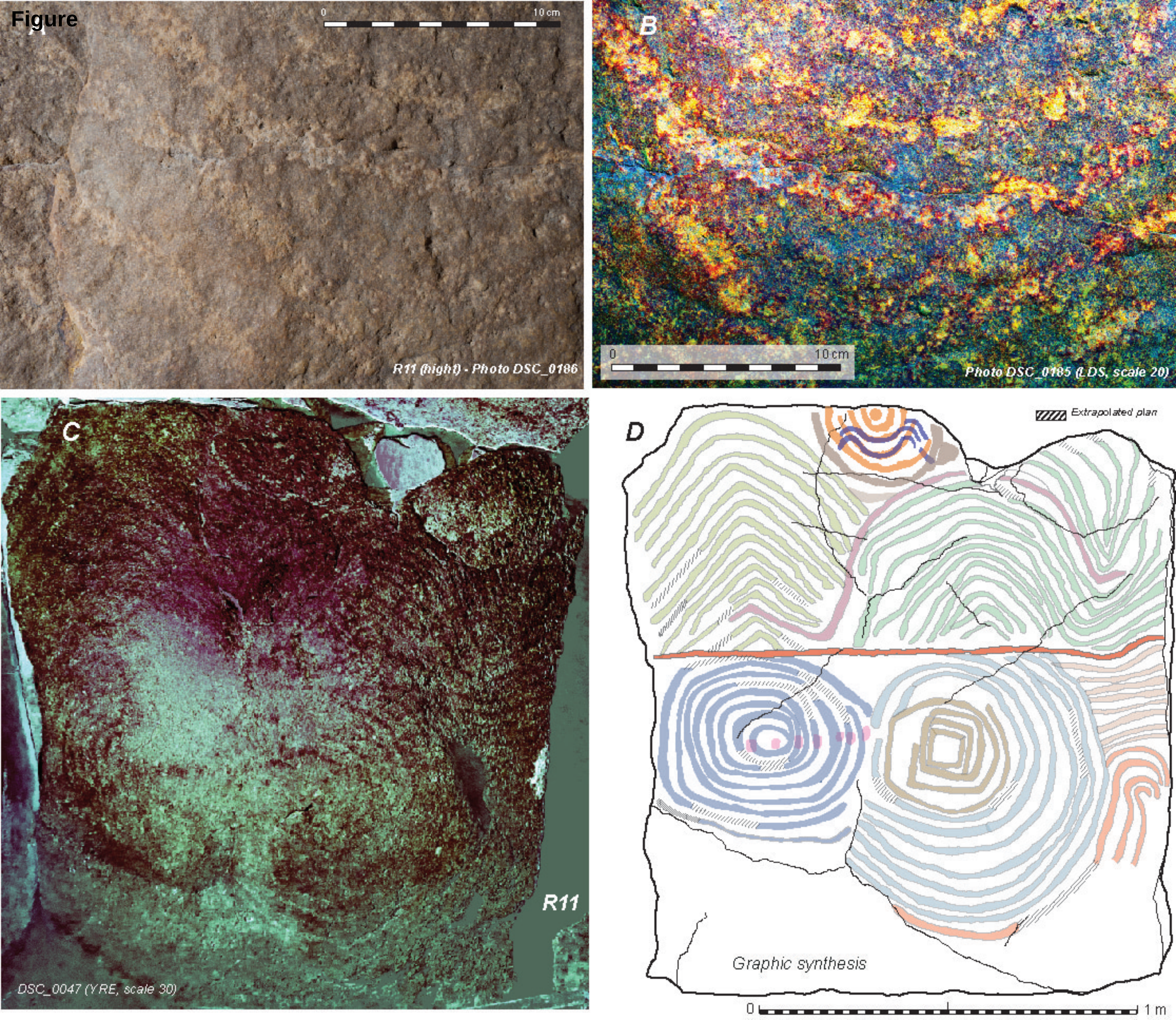


Superpositions de tracés : choix de séquences
Natural reliefs
Overlapping lines: choice of sequences
A
B
C
0
1 m
D
E
F
Tracés sans recoupements avérés
Lines without known overlaps
G
H
E9
G10
G9
G8
G7
G6
G5
G4
G3
F7
F6
F5
F4
F3
F2
F1
E8
E7
E6
B6
B5
B4
B3
B2
B1
C9
C5
C4
C8
C3
C6
C7
C2
D3
D2
H

Figure


A
Photo DSC_080
B
(Shee-Twohig 1981)
R11
0
50 cm
R 11
Deviation map by Geomagic
C
1 m
0
23 photographs under oblique turning light
D
Photos DSC_002 to 066

Figure



0
10 cm
R11 (night) - Photo DSC_0186
B
0
10 cm
Photo DSC_0185 (LDS, scale 20)
C
R11
DSC_0047 (YRE, scale 30)
D
Extrapolated plan
Graphic synthesis
0
1 m